Abouel-Seoud. 2016. *Int. J. Vehicle Structures & Systems*, 8(3), 118-125
ISSN: 0975-3060 (Print), 0975-3540 (Online)
doi: 10.4273/ijvss.8.3.01

International Journal of
Vehicle Structures & Systems
Available online at www.maftree.org/eja

Performance and Emission Evaluation of CNG as an Alternative Fuel in a Bi-fuel SI Engine Powered Vehicle

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ABSTRACT:

Alternative fuels are of much importance because of strict emission regulations, increasing fuel cost and the dramatic increase in the rate of depletion of crude oil resources. Therefore, vehicle manufacturers are shifting their research to develop vehicle engines that use alternative fuels such as compressed natural gas (CNG). However, the purpose of the present study is to measure the performance and emission characteristics of a vehicle over a wide range of its operation conditions. All the tests have been done on a passenger vehicle chassis dynamometer under transient state conditions for both gasoline and CNG fuels, where a detailed comparison has been made between their results. A bi-fuel vehicle that has been retrofitted for both fuels together with a locally produced three-way catalytic converter (TWC) that was fitted on the exhaust manifold to reduce its emissions. A multi-point injection (MPI) system is used. The results indicate that the reason behind the increase of total hydrocarbon (THC) in CNG operated vehicle over that produced in gasoline operated vehicle is due to the difficulty in oxidizing the unburned hydrocarbons in the exhaust gases, where the oxidization of hydrocarbons is one of the functions of the TWC. The exhaust hydrocarbons of a gas operated vehicle have a significantly different composition to those of a gasoline operated vehicle. Furthermore, a small deviation in the air index (λ) can be observed in all the testing times. This indicates that the use of catalyser with gasoline or CNG produces nearly same λ.

KEYWORDS:

Chassis dynamometer; Alternative fuel; Air index; Spark ignition engine; Performance; Catalytic converter

CITATION:

S.A. Abouel-Seoud. 2016. Performance and Emission Evaluation of CNG as an Alternative Fuel in a Bi-fuel SI Engine Powered Vehicle, *Int. J. Vehicle Structures & Systems*, 8(3), 118-125. doi:10.4273/ijvss.8.3.01

1. Introduction

Natural gas is a promising alternative fuel for internal combustion engines. The combustion and emission characteristics were investigated on a natural gas engine at two different fuel injection timings during the intake stroke. The results showed that fuel injection timing affects the combustion processes. The optimum spark timing (MBT) which achieved the maximum indicated mean effective pressure (IMEP) was related to fuel injection timing and air fuel ratio. At MBT spark timing, late fuel injection timing delays ignition timing and prolongs the combustion duration in most cases. But fuel injection timing has little effect on IMEP at fixed lambdas. The coefficient of variation (COV) of IMEP was dependent on air fuel ratio, throttle positions and fuel injection timings at MBT spark timing. The COV of IMEP increases with lambda in most cases. Late fuel injection timings can reduce the COV of IMEP at part loads. Engine-out CO and total hydrocarbon (THC) emissions can be reduced at late fuel injection timing [1].

Motor vehicle exhaust emissions could be sharply reduced within the past 20 years by the introduction of exhaust after-treatment systems, modern engine control concepts and cleaner fuels. However, it has not been possible to significantly improve air quality in cities with regard to particulates in the past 10 years. It has appeared that the reduction in vehicle exhaust emissions achieved was offset by the growth in traffic as well as by changes in the composition of exhaust emissions and the corresponding reactivity in the environment. The reduction of selected pollutants therefore remains an important issue alongside greenhouse gas reduction. Moreover, the results illustrate that the emissions of actual gasoline, diesel and natural gas passenger cars based on the official European driving cycle were measured; the natural gas vehicles show the lowest impact on air quality [2-3]. Two stroke spark ignition (SI) engines have high exhaust emissions and low brake thermal efficiency due to the short circuiting losses and incomplete combustion, which occur during idling and at part load operating conditions.

To eliminate the short circuiting losses, direct injection has been developed. Electronic compressed natural gas (CNG) injection system was developed for better fuel economy and reduced emissions. The fuel and time maps were generated for the various operating conditions of the engine using an electronic system. In addition, a visualization tool was used to estimate the fuel injection time and delivery quantity for required running conditions of the engine. Experiments were carried out at a constant speed of 3500 rpm with a compression ratio of 12:1. The performance and emission characteristics of direct CNG injection system and carburetted engine were described. The above studies indicate that the improvement in brake thermal efficiency was from 15.2% to 24.3%. This was mainly due to significant reduction in short circuit loss of fresh charge and precise control of air fuel ratio. Compared to a conventional carburetted engine, the HC and CO emissions in CNG injection system were reduced by 79.3% and 94.5% respectively [4].

Uniform flow distribution inside a catalytic converter is highly desirable to enhance the converter efficiency and extend the catalyst durability. Uniform flow distribution at the monolith inlet lowers local peak velocities and temperature gradients in the catalytic converter, and delays aging of the catalytic converter, while mal-distributed flow constantly results in a penalty of deterioration performance and reduced lifetime. The formation of recirculation zone inside the catalytic sensor installed in the converter diffuser, especially with closed coupled design. It is possible for a reduced-volume of close-coupled catalytic converter (CCC) to have the same durability if flow distribution becomes uniform. This leads to a reduction in cost and mass of the CCC. Generally, velocity distribution was not uniform inside the catalytic converter of production engines. This is because the flow distribution within the converter was a momentum transfer process and sensitive to different boundary conditions and momentum sources inside the system [5-6]. The exhaust emissions and performance were evaluated for a computer integrated bi-fuel SI engine that has been retrofitted for two fuels namely CNG and base fuel gasoline, under steady state with lean burn condition. The used engine was a Proton Magma, 4-cylinders SI engine. The emission results such as CO, HC and NOx were measured and compared between the above two fuels. A three-way catalytic converter (TWC) was used to assess the emissions. The results show that the arrangement of retrofitting catalytic converter and operation with lean burn condition was very effective to reduce exhaust emissions. From the performance results, it was found that CNG produced 15% less brake power, 15%-18% less specific fuel consumption (SFC) and 10% higher thermal efficiency than gasoline fuel. The emission results showed at the entrance of TWC that CNG produced 30% higher NOx emissions and lower 12% and 90% HC and CO respectively [7-8].

Performance and emissions results were recorded from running a 1.5L, 4-cylinder SI engine with gasoline and CNG under steady state operating conditions. The engine was converted to computer integrated CNG-gasoline bi-fuel operations by installing a sequential port injection CNG conversion system. An engine control system and portable exhaust gas analyzer were used for controlling the engine operations and recording the engine performance and emissions data. The engine was run at wide open throttle and constant speed ranging from 1500 to 5000 rpm with 500 rpm increment. On average, CNG yielded 22% less brake specific fuel consumption (BSFC) and 13% higher fuel conversion efficiency (FCE) compared to gasoline. It showed that CNG in sequential port injection system yielded improved BSFC and better FCE compared to carburettor system of the same engine. However, the volumetric efficiency was reduced by 4-10% with CNG operation. Due to this, the brake torque, brake power and brake mean effective pressure of the engine were reduced by 8-16%. In terms of exhaust emissions, the results showed that HC, CO and CO_2 were significantly reduced by 40-87%, 20-98% and 8-20% respectively compared to gasoline [9-10]. The vehicle engine tune-up is usually done by trial-and-error method. The vehicle is run on the dynamometer to show the actual engine output power and torques is significantly affected with effective tune-up. Current practice costs a large amount of time and money, and may even fail to tune up the vehicle engine optimally because a formal power and torque function of the engine has not been determined yet. With an emerging technique, Least Squares Support Vector Machines (LS-SVM), the approximate power and torque functions of a vehicle engine can be determined by training the sample data acquired from the dynamometer. The number of dynamometer tests for a vehicle engine tune-up can therefore be reduced because the estimated vehicle engine power and torque functions can replace the dynamometer tests to a certain extent.

Besides, Bayesian framework was also applied to infer the hyper-parameters used in LS-SVM so as to eliminate the work of cross-validation, and this leads to a significant reduction in training time. However, the construction, validation and accuracy of the functions were discussed. The predicted results were found to be in good agreement with the actual test results. To illustrate the significance of the LS-SVM methodology, the results were also compared with the regression fit using multilayer feed forward neural networks [11-13]. The above review has shown that almost of the efforts had been done directed towards studying the vehicle performance and its bi-fuel engine exhaust emissions to improve their characteristics under steady state operating conditions. Their contributions were limited by ignoring the transient state conditions. In addition, vehicle engine including catalytic conversions has also given little attention particularly that concerned with original vehicle engine. Moreover, the available measuring equipment in experimental work was limited which makes the interpretation of the experimental results rather difficult. In this paper, a research work was intended to study the performance and emissions characteristics of a bi-fuel vehicle, i.e. gasoline and CNG under the transient state conditions. In order to verify the effectiveness of the tests and estimation, a single axis chassis dynamometer tests were performed based on typical New European Driving Cycle, NEDC. A comparison between the performance and emissions characteristics of a bi-fuel vehicle in its two phases has been made. Furthermore, the effectiveness of TWC in reducing vehicle exhaust emissions has also been studied. The study was carried out on a gasoline/CNG bi-fuel vehicle (Hyundai-Star) in Egypt market.

2. Driving cycle details

The vehicle was tested over the New European Driving Cycle (NEDC). This cycle is conducted immediately following the urban cycle and consists of roughly half steady-speed driving and the remainder with accelerations, decelerations, and some idling. This driving cycle consists of two parts, ECE-15 and EUDC, that correspond to urban and highway (extra-urban) driving conditions in that order. ECE-15 test cycle simulates at an average speed of 18.9 km/h and at a maximum speed of 60 km/h. The entire cycle includes the Urban Driving Cycle (UDC) composed by four repetitions of the same module without interruption for duration of 780 seconds. The same part of the ECE-15 driving cycle is repeated four times to obtain an adequate driving distance as shown in Fig. 1. The EUDC cycle instead illustrates the aggressive, high speed driving at a maximum speed of 120 km/h and average speed is 63 km/h. In this study, only part of urban cycle with the duration of 280 seconds as shown in Fig. 2 is used. Testing is carried out by independent test organizations, either by the manufacturers or importers themselves at their own test facilities. Table 1 provides the mean parameters of first part of ECE15 driving cycle.

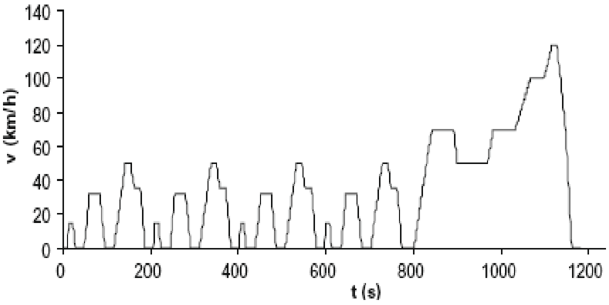

Fig. 1: New European driving cycle, NEDC

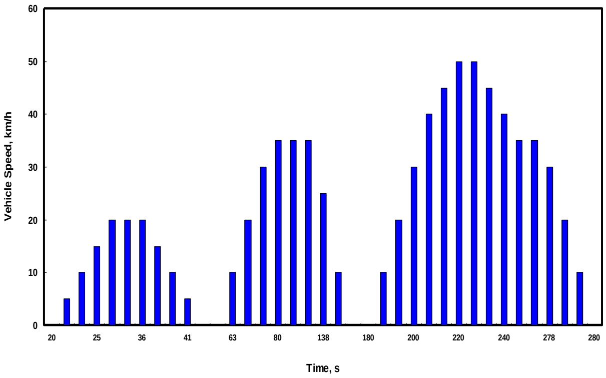

Fig. 2: Urban part European driving cycle (ECE-15)

Table 1: Drive cycle specifications

Drive cycle	NEDC
Maximum speed (km/h)	120
Average speed (km/h)	33.6
Distance (km)	1180/20
Time (s/min)	11.05
Maximum acceleration (m/s^2)	1.06
Idle (s)	298

3. Equipment instrumentation

3.1. Bi-fuel vehicle

A newly registered gasoline/CNG bi-fuel vehicle in Egypt market (Hyundai-Star) was used. The vehicle is Verna-Star, 1600 cc. The vehicle engine is SI, four strokes, four cylinders in-line and water cooled. It is transversally mounted with front wheel drive technique. The vehicle is equipped with manually operated gearbox mounted transversally and sharing the same oil sump of the engine. The gearbox offers 4-forward speed and one reversal speed. The fuel injection system used is a multi-point (MPI) sequential. The fuel properties for the vehicle used are given in Table 2.

Table 2: Fuel properties

Property	Gasoline	CNG
Chemical formula	C8H16	CH4
State	Liquid	Gas
Energy content	100%	25%
Octane rating	87-93	120-130
Auto ignition temp.	225 °C	450 °C
Stoichiometric ratio	14.7	17.3

3.2. Catalytic technology

Most modern vehicles are equipped with TWC. The converter uses two different types of catalysts, a reduction catalyst and an oxidation catalyst. Both types consist of a ceramic structure coated with a metal catalyst. The idea is to create a structure that exposes the maximum surface area of catalyst to the exhaust stream, while also minimizing the amount of catalyst required. There are two main types of structures used in catalytic converters, honeycomb and ceramic beads. A locally produced TWC is shown in Fig. 3. It has been used to reduce and assess the unwanted pollutant gases like CO, HC and NOx from the exhaust gas stream. The catalytic material consists of Platinum (Pt), Palladium (Pd), Rhodium (Rh) and cerium oxide (CeO_2). The Pt and Pd are used to oxidize CO and HC to CO_2 and H_2O. The Rh is used to reduce NOx to N_2 and O_2. However, the efficiency of the TWC depends on the availability of O_2 and the temperature in the exhaust gas stream. The role of CeO_2 in TWC is to afford as an O_2 storage capacity (OSC) which liberates or adsorbs O_2 if the air to fuel ratio is perturbed. The details about work function of CeO_2 in the TWC can be found elsewhere [14].

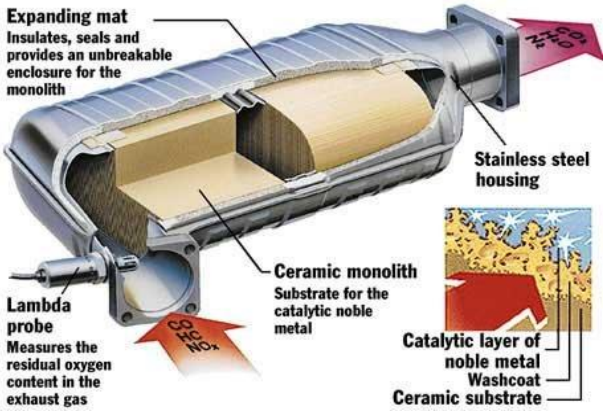

Fig. 3: Three-way catalytic converter

The catalytic bed was placed in the exhaust pipe (near the manifold) where the maximum temperature (catalytic bed temperature) reaches about 560˚C. This high temperature is required to oxidize THC (as well as un-burn CH_4) in the exhaust gas from natural gas combustion. The reduction catalyst is the first stage of the catalytic converter. It uses Platinum and Rhodium to help the reduction of NOx emissions. When a NO or

CO_2 molecule contacts the catalyst, the catalyst rips the nitrogen atoms out of the molecule and holds on to it, freeing the oxygen in the form of O_2. The nitrogen atoms bond with other nitrogen atoms that are also stuck to the catalyst, forming N_2. Catalyst system conversion efficiencies were calculated for each emissions constituent using the following equation:

$$\eta = \left(1 - \frac{Without\,Catalytic\,Converter}{With\,Catalytic\,Converter}\right) \times 100 \quad (1)$$

3.3. Chassis dynamometer facility

Vehicle performance comparisons are made on a passenger laboratory flow chassis dynamometer located in the Faculty of Engineering, Helwan University. It allows operation for a wide range of power, torque and speed modes; and performs a critical role in testing equipment for this research. Fig. 4 presents a photograph of the vehicle with chassis dynamometer and experimental equipment used during testing. It is capable of absorbing 550 HP from 460 mm diameter roll at a maximum test speed of 120 km/h. Load is controlled during testing by a pneumatic valve that controls water flow into a water break absorber attached to the roll. A hand held controller can be set to monitor and change the water flow based on a variety of control parameters including wheel speed and percent flow. The dynamometer is installed in the laboratory in a sub floor configuration. Steel plates covering the rolls and wheel channels must be removed and safely stored using a forklift before a vehicle can be loaded on the rolls. With the chassis dynamometer system power on, the vehicle chassis is centered and backed onto the rolls. The rolls must be in the locked configuration on the hand held controller to prevent them from spinning and ensure proper chassis alignment. In the final test configuration, the wheels are located forward of the center of the rolls. Once the vehicle’s front tires are secured to the floor, avoid turning the steering wheel to prevent loosening the ratchet straps. When the rolls are spinning, avoid touching the brake pedal with the handheld controller until they came to a complete stop. Samples of such chassis dynamometer are found in [15-16].

Fig. 4: Vehicle on chassis dynamometer

4. Experimental setup & testing

The laboratory tests were carried out on the vehicle that has been retrofitted for both fuels namely CNG and base fuel gasoline together with a locally produced TWC fitted on the exhaust manifold to reduce its emissions. The fuel injection system used in this work is multi-point injection (MPI) system. The vehicle was equipped with infrared gas analyzer. The exhaust gas concentration, engine rotational speed and vehicle speed are recorded during the test. Portable version of infrared gas analyzer is used during the experimental work. The gas analyzer was equipped with gas sampling probe to collect the exhaust gas from the muffler. The gas was then filtered and dried before entering the analyzer. Fig. 5 represents the layout of the gas analyzer as used in the present study, while the installation of instruments and probes in the vehicle are shown in Fig. 6.

Fig. 5: The layout of the gas analyzer

Fig. 6: The installation of probes in the vehicle

The vehicle engine is kept in its original configuration to be used as a bi-fuel engine. The CNG system used for bi-fuel converted vehicle is adopted to be seamlessly switchable between gasoline and CNG, thus providing lower power and an excellent derivability to deliver CNG into the vehicle engine for clean and efficient operation. Intensive measurements program were done at different operating condition. The selected vehicle is equipped with previously mentioned measuring instruments. The gas analyzer and its accessories are mounted in the rear seat of the passenger cabinet. Rechargeable power supply and printer are the most important attachment to the analyzer. Gas sampling probe with 3 m long inserted inside the muffler. Its other terminal is connected to the gas analyzer through the window of the rear door. Before starting the measurements, the catalyser either removed (without) or leaved (with), and the following precautions were taken into account:

- The vehicle engine is warm enough before starting the measurement and runs steadily at standard idling configuration.
- All electric accessories like electric fan and radio-cassette are off.
- All the windows of the cabinet are closed except one of the rear windows, which are partially opened (to permit the gas sampling connection). This is to keep the drag effect within the standard value.

During the tests, two persons are required to carry out the experimental work. The vehicle driver performs the test program with certain sequence and is responsible to drive the vehicle steadily for enough periods required to obtain steady measurements. The second person is the instruments operator, which is responsible to review the test procedure with the driver and observe the output readings. When the signals become steady, the output readings are recorded and next step of vehicle speed is performed. The air index (λ) was considered to represent the fuel consumption, and is defined as:

$$\lambda = \frac{(Air/Fuel)Operating}{(Air/Fuel)Stoichiometric} \qquad (2)$$

Errors and uncertainties in the tests may result from instrument selection, condition, calibration, environment, observation, reading, and test planning. Uncertainty analysis is needed to prove the accuracy of the tests. An uncertainty analysis was performed using the method described by [17]. Percentage uncertainties of various parameters like CO, CO_2, THC, λ and vehicle speed were calculated using the percentage uncertainties of various instruments. Total percentage uncertainty of these experiments for the whole experiment is obtained to be ± 2.75%.

5. Results and discussion

5.1. Vehicle driving performance parameters

Based on the experimental procedure presented in Section 4.2, Figs. 7 and 8 depict the Hyundai-star 1600 cc vehicle engine performance parameters of torque and power with respect to speed in gasoline and CNG MPI results for the European driving cycle (ECE-15) respectively. It is clearly seen that the engine torque increases as the vehicle engine speed increased up to 2750 rpm, where the maximum torque exists about 82 Nm for gasoline and about 78 Nm for CNG, and then decreased as the vehicle engine speed increased due to the occurrence of the mechanical losses. The same observation can be noticed for the corresponding vehicle engine power which reaches 31 kW for gasoline and 28 kW for CNG. The reduction of engine power and torque for CNG fuel are attributed to the following factors:

- Loses in volumetric efficiency
- Low flame speed natural gas
- Low compression ratio (CR)
- Absence of fuel evaporation

Figs. 9 and 10 depict the Hyundai-Star 1600 cc vehicle road performance parameters of power effort, torque, engine speed and vehicle speed measured on chassis dynamometer at the driving wheels at constant torque of 143 Nm in gasoline and CNG MPI respectively. The value of the vehicle speeds and power are increased as the time is increased up to 65 s with values of 130 km/h, 5200 rpm and 20 kW for gasoline phase, where the corresponding values of 48 s and 122 km/h, 4700 rpm and 18 kW for CNG phase (acceleration mode) and then decreased to 85 s for gasoline and 72 s for CNG phase (deceleration mode), where all values are nearly zero. The fluctuations in torque effort are higher for gasoline than CNG. Moreover, the building period takes 5 s for gasoline and 10 s for CNG.

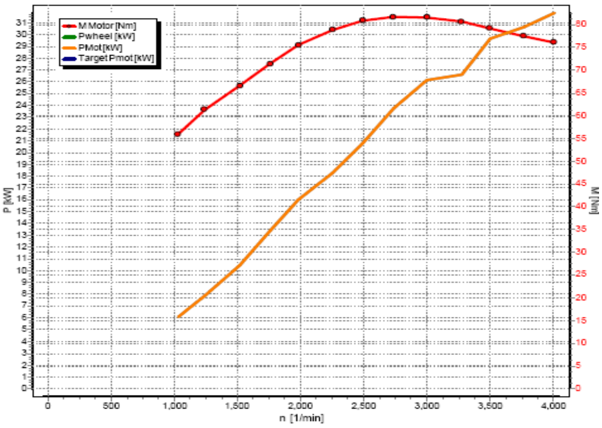

Fig. 7: Vehicle gasoline engine performance parameters

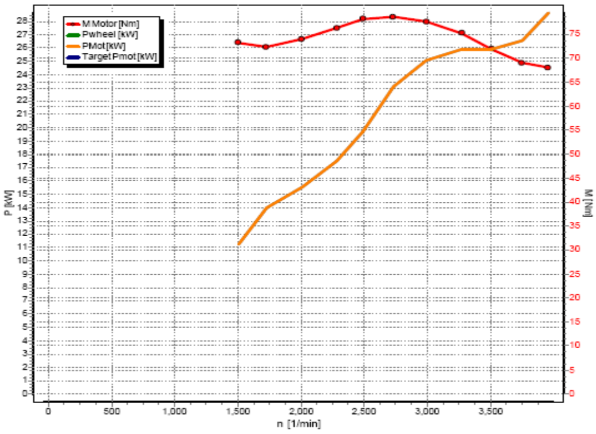

Fig. 8: Vehicle CNG engine performance parameters

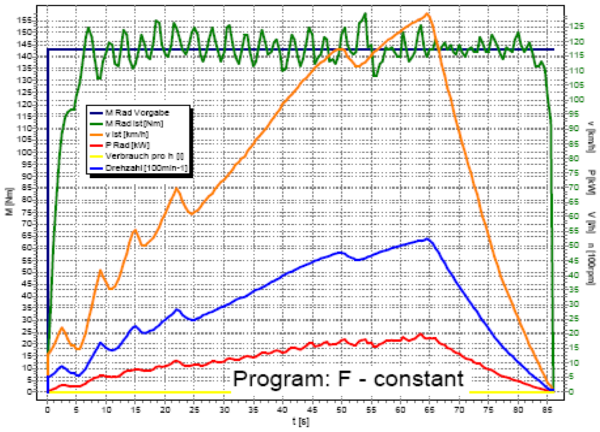

Fig. 9: Gasoline vehicle road performance parameters

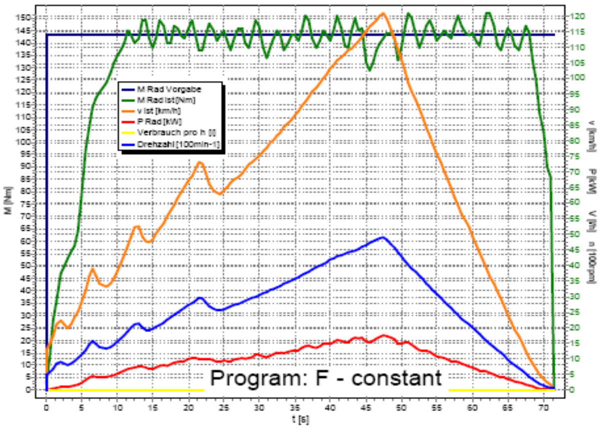

Fig. 10: CNG vehicle road performance parameters

Vehicle road accelerations are presented in Figs. 11 and 12, where the distance (S) of 145 m can be gained in about 18 s (0.447 m/s^2) for gasoline with the actual vehicle speed (V act) is 60 km/h and 450 m can be gained in about 50 s (0.180 m/s^2) for CNG with the actual vehicle speed (V act) is 60 km/h. Furthermore, high fluctuations occur in V act for CNG than that for gasoline MPI vehicle.

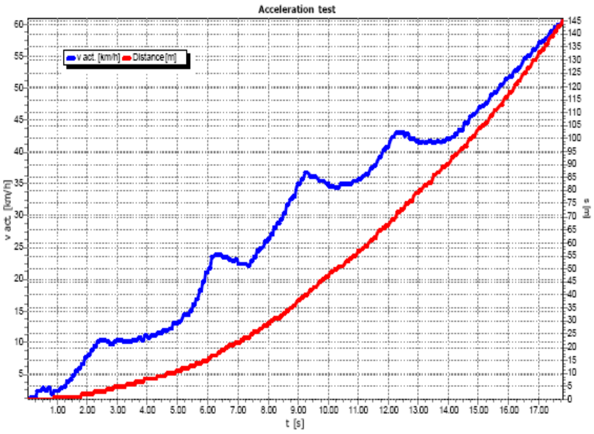

Fig. 11: Gasoline vehicle road acceleration performance

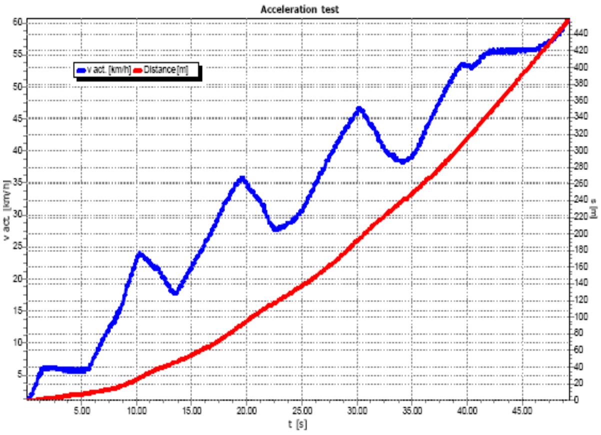

Fig. 12: CNG vehicle road acceleration performance

5.2. Vehicle emission parameters

Based on the European Driving Cycle (ECE-15), the emission pollutants of CO, CO_2 and THC measurements were obtained for the Hyundai-Star 1600 cc on the laboratory chassis dynamometer. In addition, catalyst conversion efficiency (CCE) and λ are also obtained. Figs. 13 and 14 depict the vehicle emissions component of CO results when the vehicle operates with the two fuels (i.e. gasoline and CNG). The results comprise the influence of fuel type on the CO when the vehicle is not equipped by catalyser (Fig. 13) and with catalyser (Fig. 14). It can be seen that on one hand, the results of CO emission for MPI-CNG are much lower than those measured for MPI-gasoline either with or without catalyser. On the other hand, there is a large variation in the CO emission reported for the two fuels. The variation in CO emission could be related to the differences in the combustion conditions for this vehicle. As the air-fuel ratio gets closer to stoichiometric condition, the amount of CO emission becomes less. The air-fuel ratio of CNG fuelled engine is closer to stoichiomertric condition consequently CO emissions are decreased with CNG.

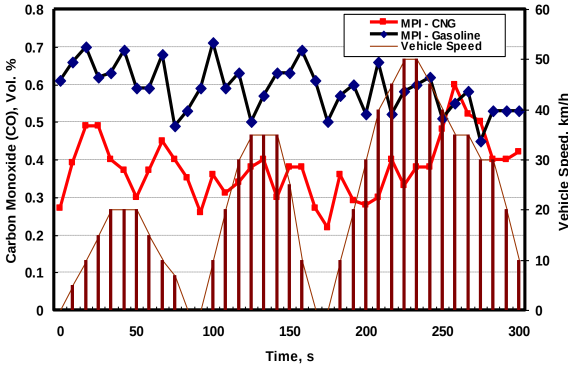

Fig. 13: CO emission without catalyser

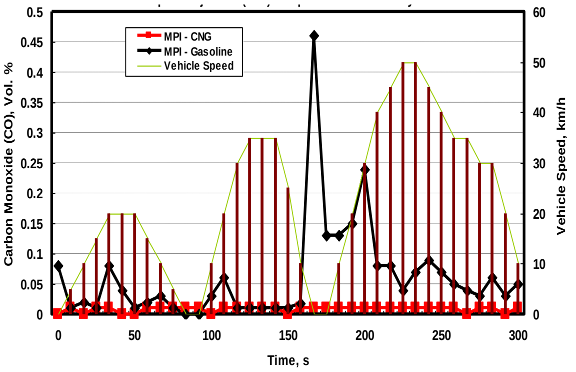

Fig. 14: CO emission with catalyser

The results of CO_2 emissions for gasoline and CNG fuel are shown in Figs. 15 and 16 respectively. It can be seen there is a large variation in the CO_2 emission reported. The amount of CO_2 in combustion of hydrocarbons is proportional to carbon to hydrogen ratio, where the main component of natural gas is methane which has the lowest carbon to hydrogen ratio compared to other hydrocarbons. Therefore, the resulting CO_2 in CNG combustion is lesser than gasoline. In Figs. 17 and 18, the influence of fuel type (i.e. gasoline and CNG) on the THC without and with catalyser respectively. The vehicle operated by CNG produces higher level of THC than that operated by gasoline. The reason behind the increase of THC in CNG operated vehicle over that produced in gasoline operated vehicle is due to the difficulty in oxidizing the unburned hydrocarbons in the exhaust gases. The exhaust hydrocarbons of a CNG-operated vehicle have a significantly different composition to those of a gasoline-operated vehicle.

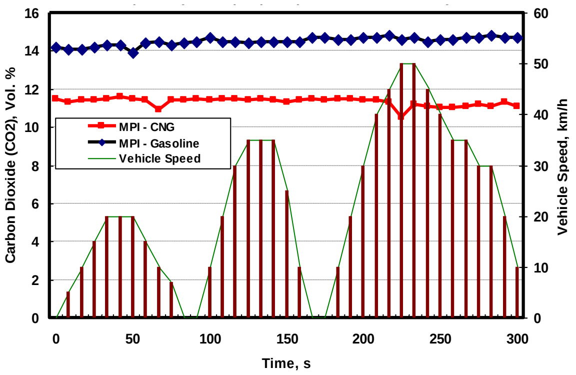

Fig. 15: CO_2 emission without catalyser

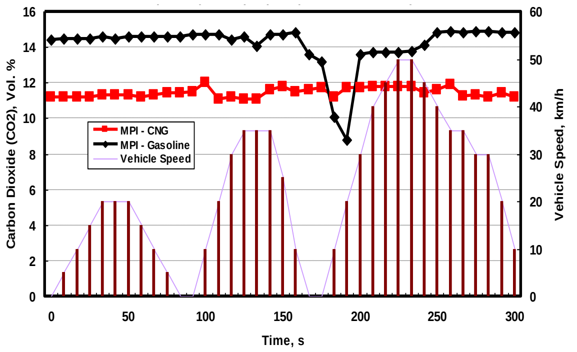

Fig. 16: CO$_2$ emission with catalyser

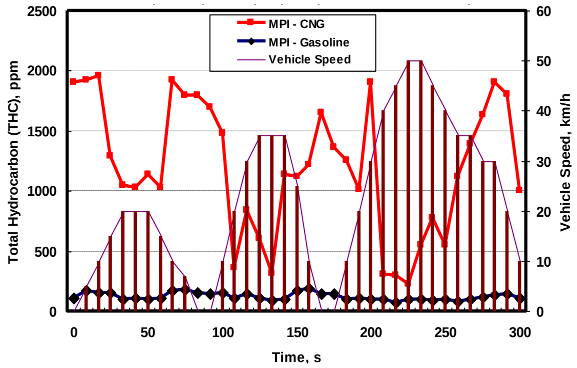

Fig. 17: THC emission without catalyser

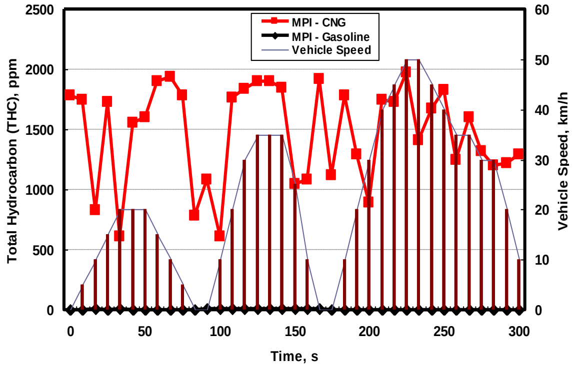

Fig. 18: THC emission with catalyser

Figs 19 to 21 show the influence of fuel type on the CCE for CO, CO$_2$ and THC levels. The CCE for either CO or CO$_2$ is much better in the case of use gasoline as a fuel than CNG as a fuel. In the case of THC, the CCE is much better in the case of use CNG as a fuel than that for gasoline. Average CCE values are plotted in Fig. 22.

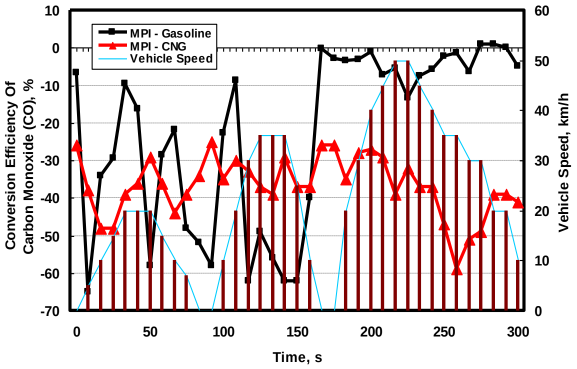

Fig. 19: Catalyst conversion efficiency of CO

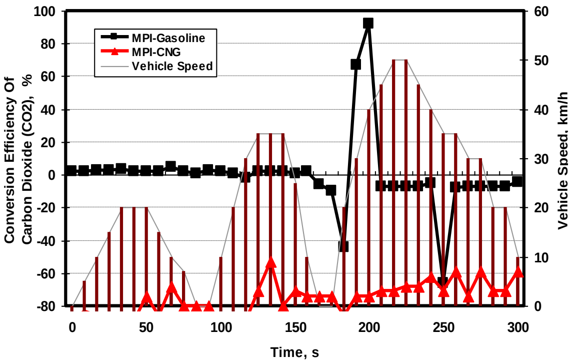

Fig. 20: Catalyst conversion efficiency of CO$_2$

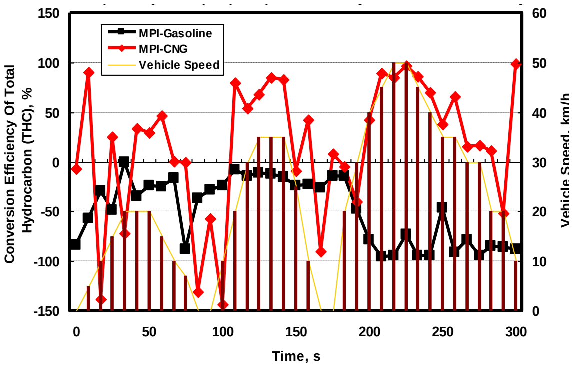

Fig. 21: Catalyst conversion efficiency of THC

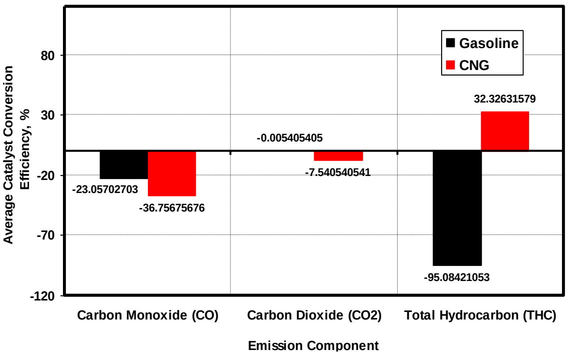

Fig. 22: Average catalyst conversion efficiency

Figs. 23 and 24 show the comparison between the measured vehicle air index (λ) for MPI gasoline and CNG with and without catalyser. A small deviation in the air index can be observed in all the testing time. This indicates that the use of catalyser with gasoline or CNG produces nearly same air index (λ).

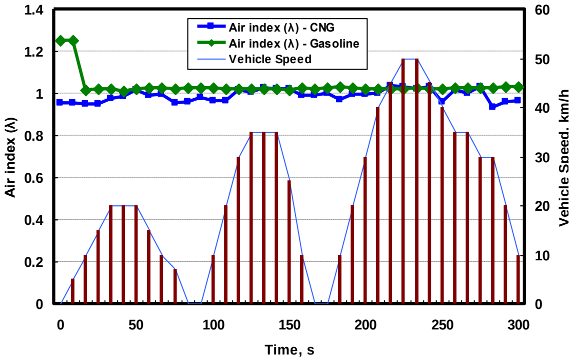

Fig. 23: Vehicle air index (λ) without catalyser

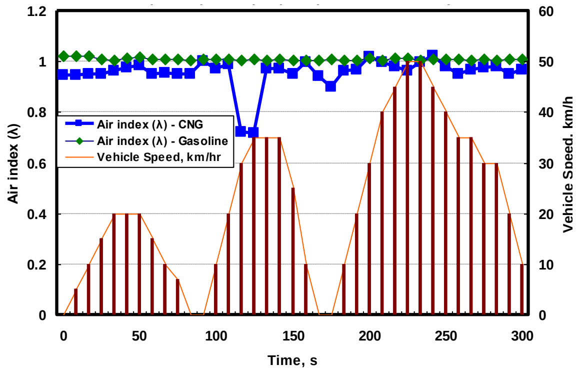

Fig. 24: Vehicle air index (λ) with catalyser

6. Conclusions

Hyundai-Star vehicle was instrumented and operated with gasoline, CNG and MPI system. Over a range of vehicle and engine speeds at transient conditions, the vehicle performance parameters are presented. For more accurate dynamometer testing as well as more robust operation of the bi-fuel vehicle platform, ECE-15 driving cycle was used. Based on transient state conditions, it is observed that the tested bi-fuel vehicle (gasoline/CNG) has the potential to meet the standards with either of the two fuels. When the vehicle was operated with CNG only, it produces less performance parameters levels than the gasoline one. Furthermore, it is found that the vehicle road acceleration produced from the vehicle operated by gasoline is 0.447 m/s^2 at V act of 60 km/h, while for CNG is 0.180 m/s^2 at V act of 60 km/h. It is observed that the reason behind the increase of THC in CNG operated vehicle over that produced in gasoline operated vehicle is due to the difficulty in oxidizing the unburned hydrocarbons in the exhaust gases, where the oxidization of hydrocarbons is one of the functions of the three-way catalyser. The amount of CO_2 in combustion of hydrocarbons is proportional to carbon to hydrogen ratio. Therefore, the resulting CO_2 in CNG combustion is less than gasoline.

The effectiveness of catalytic converter on the bi-fuel vehicle exhaust gas emissions of CO or CO_2 calculated in gasoline phase is higher than that calculated in CNG, while the case is opposite in the case of THC. Moreover, a small deviation can be observed in all the testing time. This indicates that the use of catalyser with gasoline or CNG produces nearly same air index (λ). It is hope that the results in this study can help to adopt and develop Cairo driving cycle, which is more realistic to represent Cairo traffic conditions, and can be used for tests of vehicles running in Cairo in future in order to report the real world performance of vehicles in service. Thus providing information for Egyptian's energy and environmental ministry on how to set up proper national standards for the motor vehicles fuel consumption and exhaust emissions.

REFERENCES:

[1] E. Pipitone and A. Beccari. 2007. A study on the use of combustion phase indicators for MBT spark timing on a bi-fuel engine, *SAE Technical Paper 2007-24-0051*. http://dx.doi.org/10.4271/2007-24-0051.

[2] I.I. Yaacob and N.L. A.Rahman. 2003. Zeolite catalyst synthesis: characterization and their catalytic activity reduction of gasoline exhaust gases, *Materials Science Forum*, 437-438.

[3] D.S. Burch, A. Keyser, M.P.C. Colucci, F.T. Potter, K.D. Benson and P.J. Biel. 1996. Applications and benefits of catalytic converter thermal management, *SAE Technical Paper 961134*.

[4] S. Kumarappa and G.P. Prabhukumar. 2008. Improving the performance of two stroke spark ignition engine by direct electronic CNG injection, *J. Mech. and Industrial Engg.*, 2, 169-174.

[5] H.Y. Tong, W.T. Hung and C.S. Cheung. 2000. On-road motor vehicle emissions and fuel consumption in urban driving conditions, *J. Air and Waste Management Association*, 50, 543-554. http://dx.doi.org/10.1080/10473289.2000.10464041.

[6] M.A. Kalam, H.H. Masjuki and M.A. Maleque. 2001. Gasoline engine operated on compressed natural gas, *Proc. Advances in Malaysian Energy Research*, 307-316.

[7] I.I. Yaacob, A. Hadi and N.L.A. Rahman. 2002. Evaluation of the catalytic converter performance for car engines, *Proc. 6th Asia-Pacific Int. Symposium on Combustion and Energy Utilization*, Kuala Lumpur, Malaysia.

[8] M.A. Kalam, H.H. Masjuki, M.A. Maleque, M. Amalina, A.H. Abdesselam and T.M.I. Mahlia. 2004. Air-fuel ratio calculation for a natural gas fuelled spark ignition engine, *SAE Technical Paper 2004-01-0640*. http://dx.doi.org/10.4271/2004-01-0640.

[9] H.M. Cho and H. Bang-Quan. 2009. Combustion and emission characteristics of a natural gas engine under different operating conditions, *Environmental Engineers Research*, 14(2), 95-101.

[10] T.I. Mohamad, S. Abdullah, Y. Ali, A. Shamsudeen and E. Adril. 2009. Emission of a sequential port injection Natural gas engine, *European J. Scientific Research*, 30(2), 204-214.

[11] S. Su, Z. Yan, G. Yuan, Y. Cao and C. Zhou. 2002. A method for prediction in-cylinder compound combustion emissions, *J. Zhejiang University Science*, 3(5), 543-548. http://dx.doi.org/10.1631/jzus.2002.0543.

[12] H. Namik, T. Inamura and K. Stol. 2008. *Development of a Robotic Driver for Vehicle Dynamometer Testing*, School of Engg., The University of Auckland.

[13] M.S. Kim and H.M. Hur. 2009. Braking/traction control systems of a scaled railway vehicle for the active steering test bed, *Proc. 9th WSEAS Int. Conf. Robotics, Control and Manufacturing Tech.*, Hangzhou, China.

[14] S.M. Metwalley, S.A. Abouel-Seoud and A.M. Farahat. 2011. Determination of the catalytic converter performance of bi-fuel vehicle, *J. Petroleum Tech. and Alternative Fuels*, 2(7), 111-131.

[15] M.S. Kim. 2011. Dynamometer tests of brake shoes under wet conditions for the high speed trains, *Int. J. System Applications, Engg. and Tech.*, 5(2), 143-150.

[16] S.M. Metwalley, S.A Abouel-Seoud and A.M. Farahat. 2011. Performance parameters study of bi-fuel vehicle using chassis dynamometer tests, *Int. J. Current Research*, 33(2), 76-82.

[17] J.P. Holman. 1992. *Experimental Techniques for Engineers*, McGraw Hill Publications.